The Eulerian and Lagrangian Predictability of Oceanic Flows

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LONG-TERM GOALS

To improve our capabilities and scientific knowledge concerning Lagrangian predictability in the ocean. Specific applications include search and rescue operations, the design of float and drifter experiments, and the understanding of stirring mechanisms.

OBJECTIVES

1) To identify robust geometrical structures that help distinguish regions of inherent unpredictability (Lagrangian chaos) from predictable (regular) regions.

2) Also, to identify geographical regions in the ocean where such a separation is appropriate, i.e., where Lagrangian motion is controlled by chaotic advection and not by small-scale turbulence.

APPROACH

To achieve objective (1) we use idealized models of regions or processes to identify underlying geometrical structures. The geographical extent of the Lagrangian chaos and the associated stirring and transport processes are then analyzed by finding the stable manifolds of distinguish hyperbolic points in the flow field. With regard to objective (2), we calculate measures based on dynamical systems and turbulence theory that help one to distinguish between the chaotic advection regime and fully developed turbulence. These calculations are made from ocean data or from highly resolved regional ocean models.

WORK COMPLETED

We have made good progress in mapping out the underlying geometry and the corresponding chaotic advection fields for a number of different types of current systems. The simplest case involves a single recirculation gyre trapped to a boundary. Applications include the Alboran Gyre, the Great Whirl, and various island- and ridge-trapped eddies. The underlying heteroclinic geometry in this case is known in advance and our study (with P. Miller, K. Helfrich, and C.K.R.T. Jones) has concentrated on determining how much of the eddy is in a Lagrangian chaotic state.

We have also looked into two situations in which the underlying geometry is not known in advance. The first deals with the deep western boundary current in the N. Atlantic, a flow that is now known to

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be bordered by persistent mesoscale recirculation gyres. The underlying geometry of this system is much more complicated than in the case discussed above and we (WHOI/MIT Joint Program student Heather Deese and Karl Helfrich and I) are using direct observations to attempt to piece together this geometry. Ms. Deese is also carrying out a laboratory investigation of this problem and is using dye and particle tracking imagery in order to map out the regions of Lagrangian chaos. The other region of poorly understood geometry is the deep Gulf Stream, which is thought to be dominated by eddies. We have used an idealized numerical model in an attempt to sketch out the geometry of these eddies. We have also calculated the corresponding invariant manifolds, and used the results to study chaotic transport processes which lead to mixing of fluid across the jet. This work is carried out in collaboration with Jones and WHOI/Brown postdoc Guocheng Yuan.

With respect to the second objective mentioned above, I have begun to gather together all available ocean wave number KE spectra and integral time scale information. Dr. J. LaCasce and I will also attempt to calculate Lyopunov exponents from available drifter data. This data may allow us to determine where in the ocean the separation into Lagrangian predictable and Lagrangian unpredictable regions is appropriate.

RESULTS

With regard to the Miller, Pratt, Helfrich, and Jones study of boundary trapped recirculations, the attached figure shows our model recirculation for four parameter settings (corresponding successively to stronger wind forcing). The center of recirculation is shown as closed streamfunction contours and the colored regions correspond to fluid in chaotic motion. As shown, the chaos generally occurs around the edge of the recirculation and along the coastline. It does not penetrate into the very center of the recirculation or into the ocean interior. A person lost overboard in the colored area would drift in a chaotic manner and would be harder to locate than someone falling overboard inside or outside of the colored area. The colored regions have been mapped out by plotting the stable and unstable manifolds of the hyperbolic points just to the north and south of the gyre. The lobes formed by the intersections of the manifolds contain fluid in Lagrangian chaotic motion. The volume fluxes associated with the chaotic motion have been found to increase in proportion to the cube of the boundary layer Reynolds number. We have also examined this gyre in a laboratory model and have obtained the first known visualization (a video) of an invariant manifold.

Results for the model of the deep Gulf Stream (with Yuan and Jones) are less quantitative and speak more to changes in underlying geometry that occur as the depth increase. We have observed a number of geometrical transitions, including merger and 'reconnection' of cat's eye structures, as the depth varies. Such changes proved to be more elaborate than expected and suggest that drifter strategies for measuring the Gulf Stream and other baroclinic jets require careful, depth-dependent initialization.

Ms. Deese's laboratory experiment is recently up and running and results are only beginning to come in. The same can be said for my assessment of chaotic advection in the ocean.

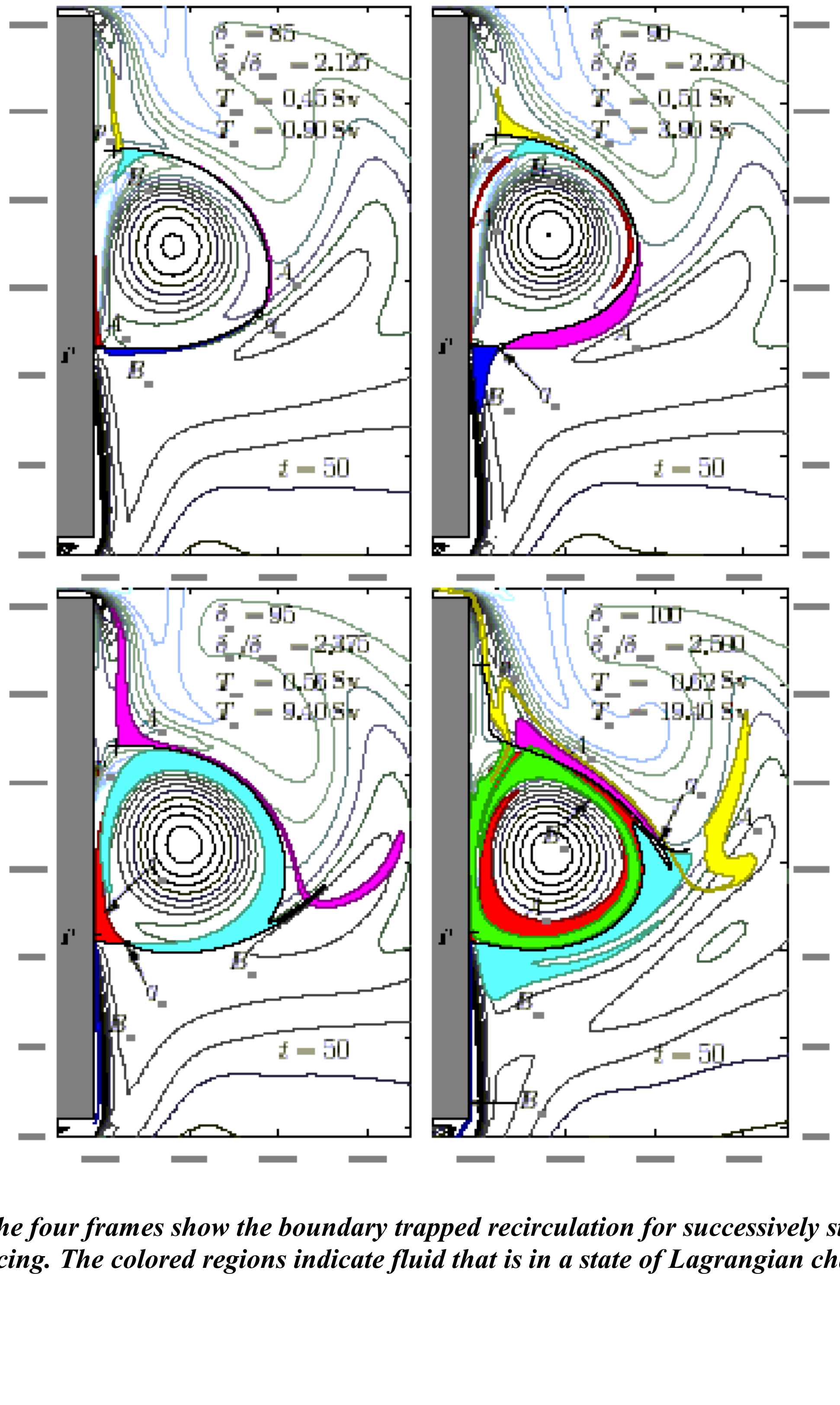

Figure 1: The four frames show the boundary trapped recirculation for successively stronger wind forcing. The colored regions indicate fluid that is in a state of Lagrangian chaos.

IMPACT/APPLICATIONS

TRANSITIONS

Deese's and Helfrich's use of dye and particle tracking technology is the first attempt to reconstruct stable and unstable manifolds in a laboratory experiment. These procedures may be of interest to a wide variety of laboratory investigators.

RELATED PROJECTS

The publication process for manuscripts prepared under my previous ONR award (a study of the Bab al Mandab) nears the final stage. Three papers (Pratt et al 1999 and 2000a and 2000b) are now in print and a third (Deng et al) is in the final stages of preparation.

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